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RESEARCH AND DEVELOPMENT OF AN ADVANCED PERSONAL LOAD CARRIAGE MEASUREMENT SYSTEM

Phase IV: Section G
Analysis of Human Responses to Load Location in a Back Pack

by

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Executive Summary

The purpose of this study was to determine the effect of varying the centre of gravity of the load on physiological, biomechanical, and subjective factors of experienced soldiers. A secondary purpose was to examine the relationship of these factors to a standardized load carriage (LC) simulator test. Twenty-two experienced soldiers marched on a treadmill at 5.6 km/hr for 15 minutes carrying a modified backpack, created by US Army Natick Research Laboratory, which consisted of the ALICE pack frame and a movable load box containing 36 kg. In addition, a load carriage vest was used to examine a balanced load distribution. Physiological measures were collected using oxygen consumption (VO2) and heart rate. Biomechanical measures were collected from video images of gait to calculate trunk and body lean. Subjective measures were recorded of pressure points using a body scan image, as well as general assessments of each system and an overall ranking. Physiological measures were not able to discern statistical differences between load locations, perhaps because of the short test duration. Biomechanical measures revealed that trunk and body lean were significantly reduced with the balanced method, followed by the higher centre of gravity load location. Subjective results revealed an overall preference for a balanced load, except for its associated heat stress, with the next most favoured load location being a high centre of gravity. The same pattern of biomechanical values was revealed through a decreas in Fx with lower load locations and an increas My with higher load location when the LC Simulator was used to test each condition. Pressure measurements were all above 20 kPa with the balanced load having reduced pressures in comparison to other strategies. Average pressures in the lumbar and iliac crest areas increased as the load was moved down the back, but the total shoulder pressures remained unchanged. It was concluded that, for marching order, balanced loads outperform all other backpack strategies, although thermal stress needs to be overcome. The next best solution is one that has the centre of gravity of the load at a high location in the pack.

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1.0 Introduction:

Load carriage is a task, which requires additional energy to maintain or move the body plus the load. To date, few studies have focused on the effects of varying the center of gravity of the load either with respect to the pack, or the subject's back (3, 18, 31). Most attention has also been directed toward the effects of external load (2, 5, 7, 11, 12, 17, 18, 22, 23, 24, 25, 29), with equations developed to approximate oxygen consumption for loaded gait, for a given terrain, grade, speed, load, and subject mass (23). Many researchers have concentrated on attempting to maximize the load carried by the soldier while at the same time minimizing the energy expended (6, 7, 11, 22, 23, 25, 26, 27, 28, 29). No studies were able to discern physiological difference between high, medium, and low load locations in a backpack.

From a biomechanical perspective, load carriage studies have focused on gait changes with increased loads (18, 31). Studies have suggested that the most reasonable load location is as close to the body's center of gravity (COG) as possible. This placement reduces excess moments about the body's COG, and thus reduces the energy required to carry the load (3, 15, 31). Bobet *et al.* (3), however, suggested placing the load below the body's COG would be ideal due to the lower moments and forces arising from angular and linear accelerations of the load and trunk. However, this low load placement would require greater forward trunk or body lean for gait where the COG must be moved in front of the base of support.

Some load location studies have also shown that the use of a double pack, which holds equal loads on the front and back of the body, elicits a lower physiological cost (5, 15). Some studies of double packs, as well as load carriage vests, have shown that subjective ratings of exertion and heat stress increased when using these carrying methods due to lack of skin surface ventilation. Another downfall associated with double packs and load carriage vests is an increase in task performance time

when compared to the standard backpack, due to bulkiness of the double pack as tested in a 20 km road march (13). Decreased mobility has also been associated with having a pack on the front of the body (10, 15). No studies were conducted which related to the biomechanics of the gait pattern or adequately compared energy costs with a variety of load locations.

The purpose of this study was to determine the effect of varying centre of gravity of the load on physiological, subjective and biomechanical factors of experienced soldiers. A secondary purpose was to examine the relationship of these factors to a standardized load carriage simulation test. This secondary purpose has been made possible because of an instrumented load carriage simulator that has been developed at Queen's University. This simulator has been used to develop a standardized assessment for load carriage systems such as backpacks and load carriage vests. It consists of a 50^{th} percentile anthropometrically weighted male manikin that oscillates in a sinusoidal manner to simulate human gait. It is instrumented with a six degree-of-freedom load cell at the hips, Tekscan FSCAN® pressure measurement system on the shoulders and waist and Polhemus FASTRAK® system to examine relative motion between the pack center of mass and the person. Nine military load carriage systems were correlated with specific human factors measurements. In total, 21 of 39 simulator measurements exhibited a significant correlation ($p < 0.05$) with human factors measurements recorded from expert military subjects Included in these correlations were: mean hip moments (M_x, M_y, M_z), mean hip reaction forces (F_y, F_z). In addition, average shoulder pressure in the anterior shoulder, as well as the peak pressures in the anterior and posterior shoulder, were highly correlated to human factors measures of comfort and sub-components of comfort (e.g. shoulder, neck, hip, march acceptability and comfort) and various measures of overall mobility (e.g. torsional, forward flexion, balance, lie function, reaching, and doffing the pack).

2.0 Methods:

2.1 Subject Selection and Equipment:

The 22 participants were male soldiers from the 1st Canadian Division Headquarters Signals Regiment at Canadian Forces Base Kingston (CFB Kingston), Ontario, Canada. Military subjects were used to ensure safety, and familiarity with heavy load carriage and its associated discomfort. The subjects had no prior history of back pain or other medical maladies that would hinder their participation in this experiment. Prior to participating, all subjects completed a PAR-Q and a consent form in accordance with ethics requirements for human subject use set out by Queen's University at Kingston.

The soldiers carried a payload of 36.0 kg (79.4 lb.) for three trials. The payload was a backpack constructed by the U.S. Army Bureau of Research and Development, Natick, MA that consisted of a U.S. ALICE pack frame and suspension system, with a load carriage box attached to the rear of the pack. The box contained lead weights that were moved along the frame by turning a screw drive on the top of the pack frame (Figure 1). The distance between the low, middle and high COG locations was 13.3 cm for a total spread of 26.6 cm from highest to lowest position. The fourth load carriage strategy incorporated the use of a Rapid Prototype Load Carriage Vest (Human Systems Inc.). It had a Velcro™ exterior covering that allowed for pocket attachment on any part of the vest. The vest pockets on the front and back were filled with an even distribution of 36.0 kg weight and were held in place by both the Velcro™ and two belts that were wrapped around the subject and the pockets (Figure 2). This alternate configuration reduced excess moments on the body by keeping the load close to the body's center of gravity.

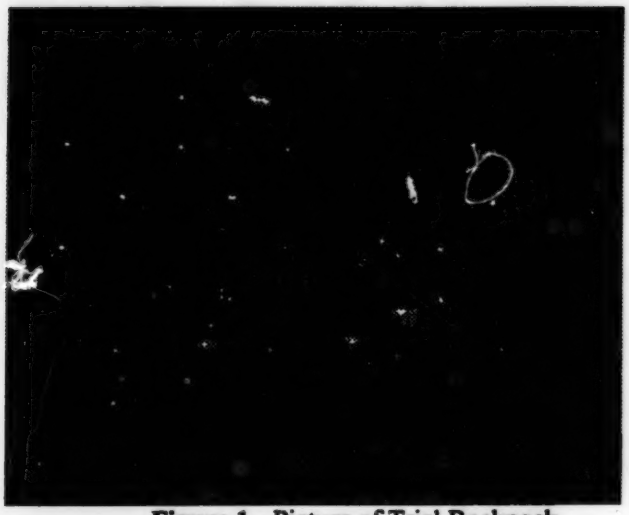
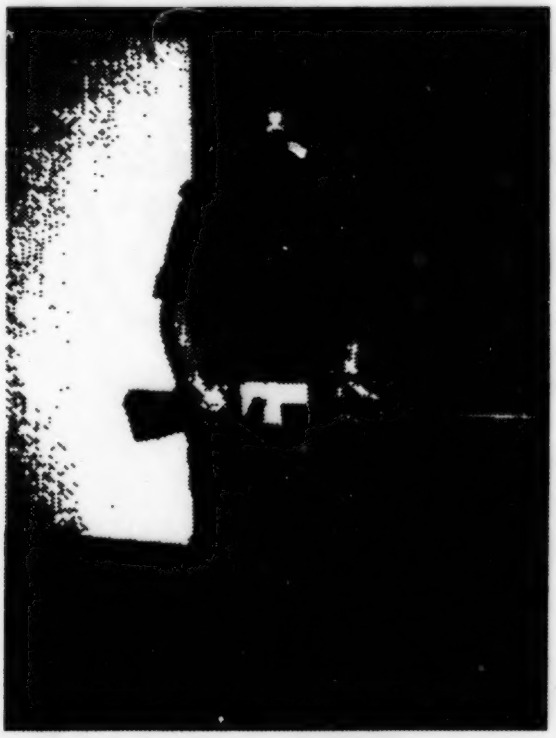
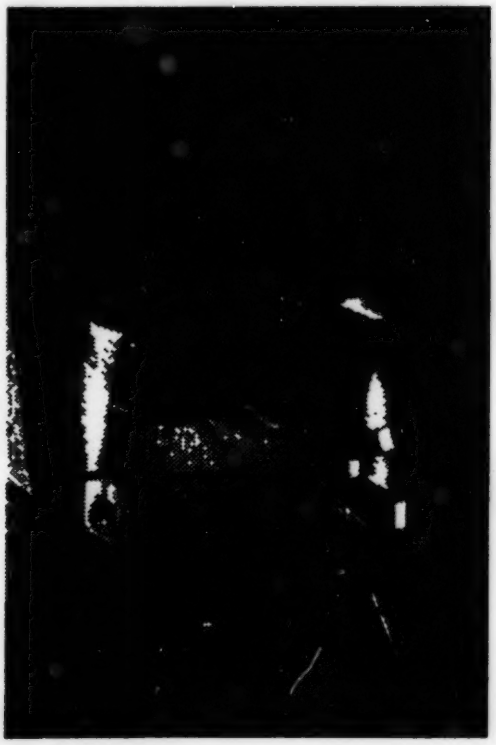


Figure 1 - Picture of Trial Backpack

Figure 2 – Picture of Alternate Load Carriage System





2.2 Protocols for Human Trials:

Prior to testing, the subjects participated in a 20 Metre Shuttle Run (20 MSR) maximal oxygen consumption (VO_2 max) test (14). Subjects were selected after this test so as to minimize the variability due to fitness levels between subjects. The laboratory tests consisted of fifteen-minute walking sessions at 5.6 km/h (3.5 mph) on a level grade on a Star Trac® treadmill. The human testing occurred over a period of two non-consecutive days and, for each test, a technician lifted and adjusted the backpack into position.

At each session, subjects performed a baseline (unloaded) trial in order to determine the energy required to perform the test that day. During analysis, the baseline values were subtracted from the loaded-trial values and divided by the subject's maximum oxygen consumption (VO_2 max) in order to obtain test values that were percentages of maximum oxygen consumption in excess of baseline. This procedure was used to normalize the influences of variable aerobic capacity on outcome measures. A complete block design with randomized trials was employed.

Two one minute time segments of the test were recorded by Hitachi video camera for later analysis. The first recording took place during the second minute of activity and the second recording took place during the fourteenth minute. The biomechanical analysis that followed the collection of the video images consisted of digitizing the joint centers (head, shoulder, hip, elbow, wrist, knee, ankle and toe) during the mid-stance phase of the gait cycle when the contralateral limb was in mid-swing. Total lean angle and the trunk lean angle were analyzed. Trunk lean comprised the angle, subtended between the vertical and the hip (greater trochanter) to shoulder (head of the humerus) line. Total lean angle comprised the angle subtended between the vertical and the ankle (lateral maleolus) to shoulder line. Metabolic information was

collected using the Teem Portable Metabolic Cart. Analysis of the physiological and human biomechanical data consisted of repeated measures ANOVA on normalized data.

The subjects filled out a post-test rating questionnaire following every test which asked about acceptability of the load position, marching balance, load control, ease of mobility, physical comfort, and thermal comfort The questionnaire also asked subjects to specify the location of any discomfort on the front or back of the body that was felt during any portion of the test. Rating scores ranged from 'No discomfort' (score of zero) to 'Extreme discomfort' (score of nine). Subjects were also asked whether the load was in a good position for them and asked whether or not they would be comfortable marching with the load in that position. Initial rating questionnaire results were treated with the Friedman test of significance.

Following completion of all parts of the protocol, subjects were asked to rank the changed COG locations from best to worst as well as give reasons for their choices. Subjects also commented on whether a particular load placement caused them to work harder than another. The results of this questionnaire were treated with the Friedman test of significance and *post hoc* simultaneous statistical inference tests.

2.3 Protocol for Standardized Load Carriage Simulation Tests

A dynamic load carriage simulator (LC Simulator) was used to examine the biomechanical effects (moments, forces and surface pressures) of varying the load location on the body (30). The simulator consisted of a 50th percentile male, anthropometrically weighted manikin torso mounted on a 6 degree-of-freedom load cell that was aligned with the neutral axis of the manikin at approximately the L5-S1 level. This manikin was attached to a steel platform, which was further attached to three computer controlled pneumatic actuators that moved the platform up and down at 1.8 Hz in a manner similar to normal human gait. The manikin's forward lean for balance was accomplished by adjusting a single axis articulating vice to a lean angle that balanced the moments of the manikin plus load. Strap force transducers, placed on the left shoulder strap and the left rear portion of the waist belt, were used to standardize strap tensions across the test groups.

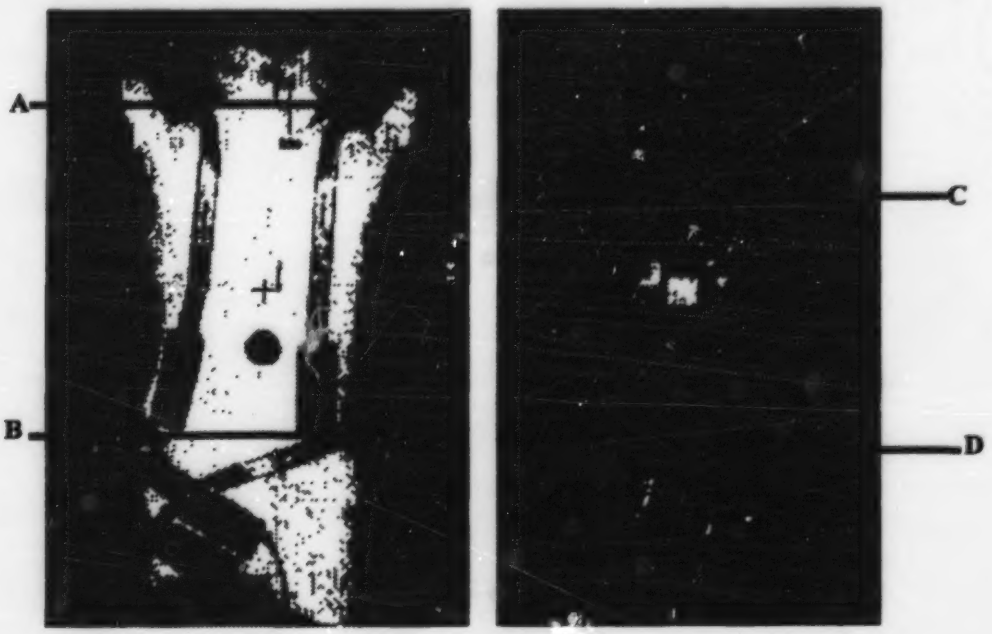
Ground reaction forces and moments were collected using a 6 degree-of-freedom load cell based on a fixed body coordinate system oriented along the long axis of the trunk. The force results from this load cell were reported as resultant mean force (F) which were the vectorial combination of the reaction forces F_x (antero-posterior), F_y (medio-lateral) and F_z (cranial-caudal). In the same fashion, the resultant mean reaction moments (M) were calculated where M_x were medio-lateral moments, M_y were anterio-posterior moments and M_z were torsional moments. Normalization of these results was performed by subtracting the baseline reaction forces and moments of the manikin alone, and then normalized by pack payload mass.

An F-Scan® pressure sensing system was used to examine the contact pressures on the manikin over the anterior and posterior shoulder, upper lumbar and iliac crest, under all four load

conditions. Figure 3 shows the orientation of the sensors used in the testing. Data were reported in both average and peak pressure measurements.

Each test cycle consisted of a 1200-second simulated march with data recorded at 10 seconds and then every 300 seconds until the end of the test. Outcome measures were hip reaction forces and moments, amplitudes of the reaction forces and moments and skin contact pressures on the anterior and posterior shoulder, upper lumbar and iliac crest.

Figure 3 – Front and back of LC simulator manikin demonstrating the location of pressure sensors (A = anterior shoulder, B = iliac crest; C = posterior shoulder; D = upper lumbar)



3.0 Results:

3.1 Human Results

The twenty-two subjects used in this study averaged 28.0 ± 4.4 years in age and weighed 87.0 ± 8.4 kg. Their average maximum oxygen consumption was 47.3 ± 3.1 $ml \cdot kg^{-1} \cdot min^{-1}$ which represents 55-60th percentile fitness scores for mean age based on the Canada Fitness Survey (8).

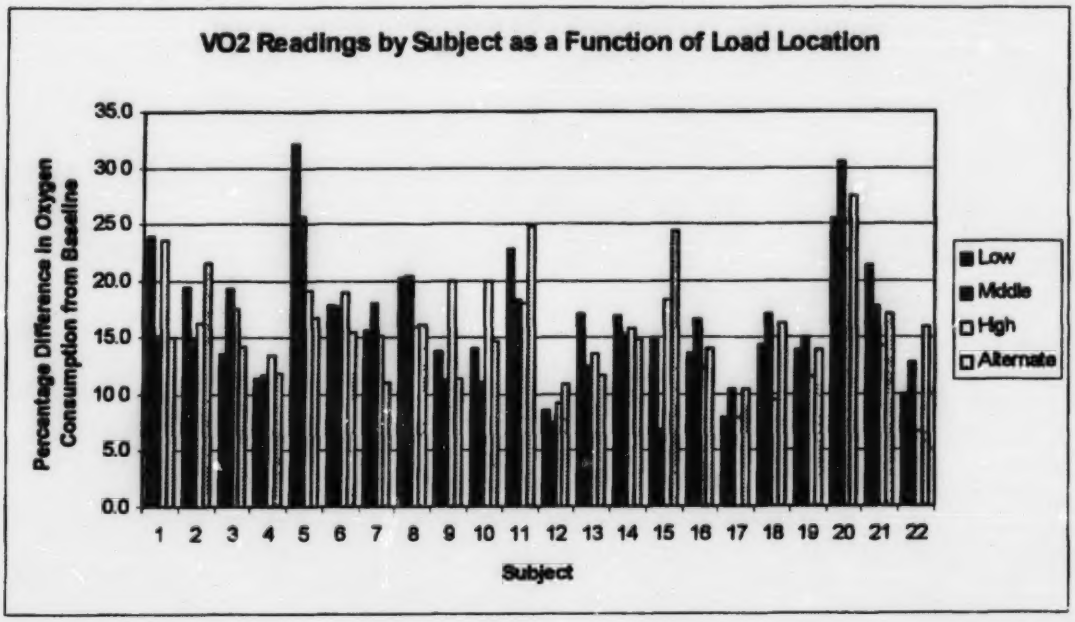
3.1.1 Physiological:

Table 1 shows the mean differences from baseline of the percent VO_2 maximum readings for each of the trials. Repeated measures ANOVA on the location of the load and the resulting physiological energy cost showed that there were no significant differences between any of the load locations under the conditions examined in this study ($p = 0.621$). Figure 4 shows an overview of the energy costs for all subjects by load location.

Table 1 - Mean Difference in Percent Maximum VO_2 Readings from Baseline.

LOAD LOCATION	TEST AVG (SD)	BASELINE AVG (SD)	% MEAN DIFFERENCE FROM BASELINE (SD)
Low	55.08 (8.22)	38.38 (4.81)	16.79 (5.83)
Middle	53 80 (8.22)	38.38 (4.81)	15.75 (5.48)
High	53 70 (8.01)	38.38 (4 81)	15.46 (4 62)
Alternate	55 05 (7.46)	38 38 (4.81)	15 92 (4.72)

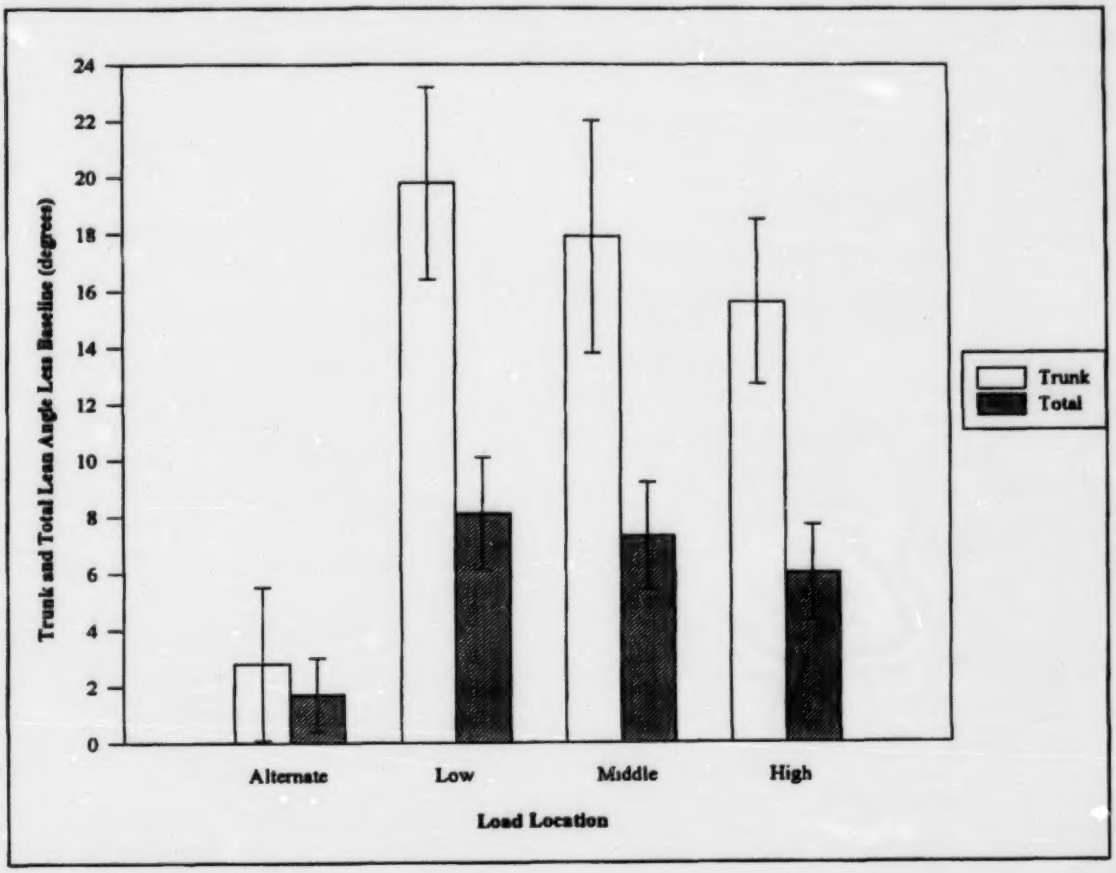
Figure 4 - Difference in Percent Maximum VO_2 as a Function of Load Location – All Subjects.



3.1.2 Biomechanical (Human):

Figure 5 shows the mean and standard deviation of trunk lean and total lean from baseline as a function of load placement. The lower the load was placed the larger the forward trunk lean. The distribution of the load across the front and back of the subject led to the least deviation of trunk lean from the baseline.

Figure 5 – Mean and Standard Deviation Trunk Lean Angle Difference from Baseline as a Function of Load Location



Using one-way ANOVA there was a significant difference in trunk angles ($p < 0.001$) and total lean angles ($p < 0.001$) adopted by subjects, when grouped by location of the load. Tukey *post hoc* statistical tests (Table 2) showed that significant differences existed between all 'alternate' permutations as well as between low and high load locations ($p<0.05$).

Table 2 – Tukey Post Hoc Multiple Comparison for Trunk and Total Body Lean Data.

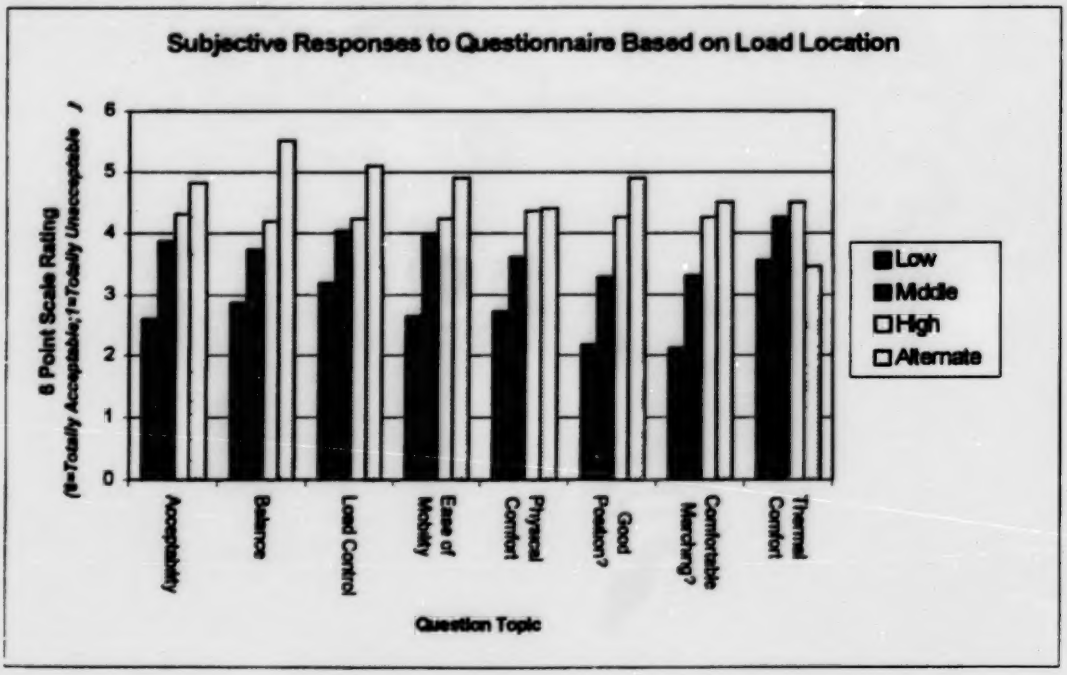
LOCATION COMPARISONS	q (trunk)	$p < 0.05$	q (total)	$p < 0.05$
LOW VS ALTERNATIVE*	**26.819**	**Yes**	**17.283**	**Yes**
LOW VS HIGH*	**6.550**	**Yes**	**5.521**	**Yes**
LOW VS MIDDLE	3 020	No	2 255	No
MIDDLE VS ALTERNATIVE*	**23.799**	**Yes**	**15.028**	**Yes**
MIDDLE VS HIGH	3 530	No	3 267	No
HIGH VS ALTERNATIVE*	**20.269**	**Yes**	**11.762**	**Yes**

* indicates statistically significant difference ($p<0.05$)

3.1.3 Subjective:

Figure 6 shows that the low pack position was rated least acceptable in 7 categories examined on the subjective questionnaire. The alternate configuration was rated most acceptable in all categories except thermal comfort where it was rated least acceptable.

Figure 6- Mean Responses on Subjective Questionnaire



In a follow-up questionnaire, subjects were asked to rank the load locations from best to worst (assigning numbers 1 through 4 respectively). The balanced load configuration was preferred overall with statistically significant differences ($p < 0.001$). *Post hoc* simultaneous statistical inference (Table 3) showed that there were statistically significant differences between all permutations except alternate and high.

Table 3 – *Post Hoc* Simultaneous Statistical Inference.

LOAD LOCATION	LOW	MIDDLE	HIGH	ALTERNATE
LOW	0	-1.1*	-2.3*	-2.6*
MIDDLE	1.1*	0	-1.1*	-1.5*
HIGH	2.3*	1.1*	0	-0.4
ALTERNATE	-2.6*	1.5*	0.4	0

* indicates statistically significant difference ($p<0.05$)

Results showed that 91% of subjects ranked the low-load configuration as last or second to last choice with the most common reported problem identified as excessive body lean and undue stress on the lower back. Other common responses are noted in table 4.

Table 4 - Common Responses and Perceptions of Load Location.

LOAD LOCATION	COMMENTS
Low	-excessive body lean -undue stress on lower back -joint pain -increased ventilation -pain in shoulders -high pressure on the neck, shoulders and lower back
Middle	-reasonable -pain due to increased lean -good stability and balance
High	-too hard on the lower back and shoulders -good walking posture -poor load stability -unacceptable for uneven terrain
Alternate	-thermally uncomfortable -great weight distribution -good maneuverability -excellent balance and posture -no excessive back stress -increased pressure on top of shoulders -restricted breathing due to tension straps -VERY little pressure on the body

3.2 Dynamic Load Carriage (LC) Simulator:

3.2.1 Reaction Forces and Reaction Moments:

Table 5 shows the values of reaction forces and moments for all load distributions. Specific variables of interest are F_x (anterio-posterior forces), M_y (anterio-posterior moments) and M_z (torsional moments). The average reaction forces for the four load locations steadily decrease in the F_x direction from low, middle, high and then to alternate. The moment (M_y) increased linearly with lean angle (from alternate to high to middle to low). In the M_z direction, the alternate load location elicited the lowest moment followed by the middle then low and high locations.

Table 5– Summary of Reaction Forces and Moments for All Load Locations

Load Location		Force* (N)	Normalized Force (N/kg)	Moment* (Nm)	Normalized Moment (Nm/kg)
Low	X	353 40	9 82	-3 80	-0 11
	Y	-96.60	-2.68	-8 00	-0.22
	Z	296.80	8.24	-2.00	-0.06
	R	471.50	13 10	9 08	0.25
Middle	X	316.60	8.79	-3 00	-0.08
	Y	-86.40	-2.40	-5.80	-0 16
	Z	294.60	8 18	-2 00	-0 06
	R	441 01	12.25	6.83	0 19
High	X	293 00	8 14	1 00	0.03
	Y	-93.00	-2.58	-3.00	-0.08
	Z	315.67	8.77	-3 00	-0.08
	R	440 62	12.24	4.36	0 12
Alternate	X	41 60	1 16	-3.00	-0.08
	Y	-95.40	-2 65	-0.80	-0 02
	Z	332 00	9.22	0 00	0.00
	R	347 93	9 66	3 10	0 09

* Baseline forces and moments due to lean angle and body weight are removed to allow for comparison.

3.2.2 Pressure Measurements:

The pressure measurements during the testing of the four load distributions are listed in Table 6. The information presented consists of the location of the sensor, the average pressure for one recording sequence (10 seconds), and the peak pressure during that sequence. The sensors that have 'n/a' listed are sensors that did not detect any significant pressure in that area.

Table 6 – Summary of Pressure Sensor Measurements for all Load Locations

Load Location	Sensor Location	Average Pressure (kPa)	Peak Pressure (kPa)
Low	Anterior Shoulder	18.2	46 2
	Posterior Shoulder	22 3	37 6
	Upper Lumbar	55.1	65.1
	Iliac Crest	23 6	44.3
Middle	Anterior Shoulder	18 9	48 5
	Posterior Shoulder	23	32.4
	Upper Lumbar	32.4	87.2
	Iliac Crest	27 1	63.3
High	Anterior Shoulder	19.8	48.5
	Posterior Shoulder	22.3	37.6
	Upper Lumbar	33.5	103
	Iliac Crest	n/a	n/a
Alternate	Anterior Shoulder	17.4	41.6
	Posterior Shoulder	9 75	14 6
	Upper Lumbar	n/a	n/a
	Iliac Crest	n/a	n/a

Using 20 kPa as the reference point for acceptable average pressure based on soldiers' responses (30), posterior shoulder pressures and upper lumbar pressures were exceeded in all cases except the alternate load location. The iliac crest pressures were only significant during the low and middle load locations.

Peak pressures, indicative of a high point pressure area, were not significantly different in the anterior shoulder but were less in the posterior shoulder of the alternate system. Again only low and middle loads had peak pressures in the iliac crest area with the largest lumbar peak pressure (103 kPa) exhibited by the high load location.

Figures 7 and 8 show pressure plots for the anterior shoulder and posterior shoulder for all tested load locations.

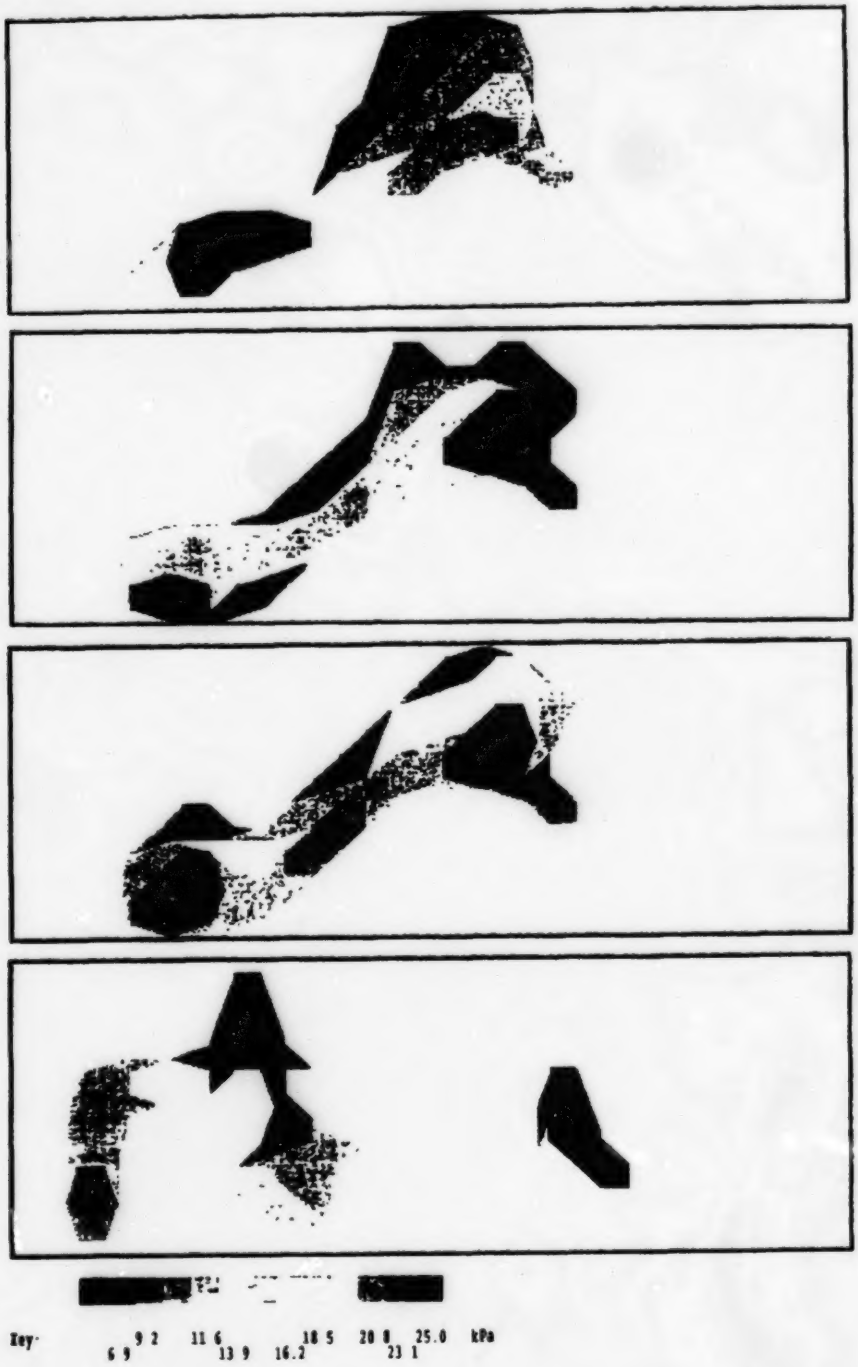


Figure 7 – Pressure plots for anterior shoulder for low, middle, high and alternate load locations respectively

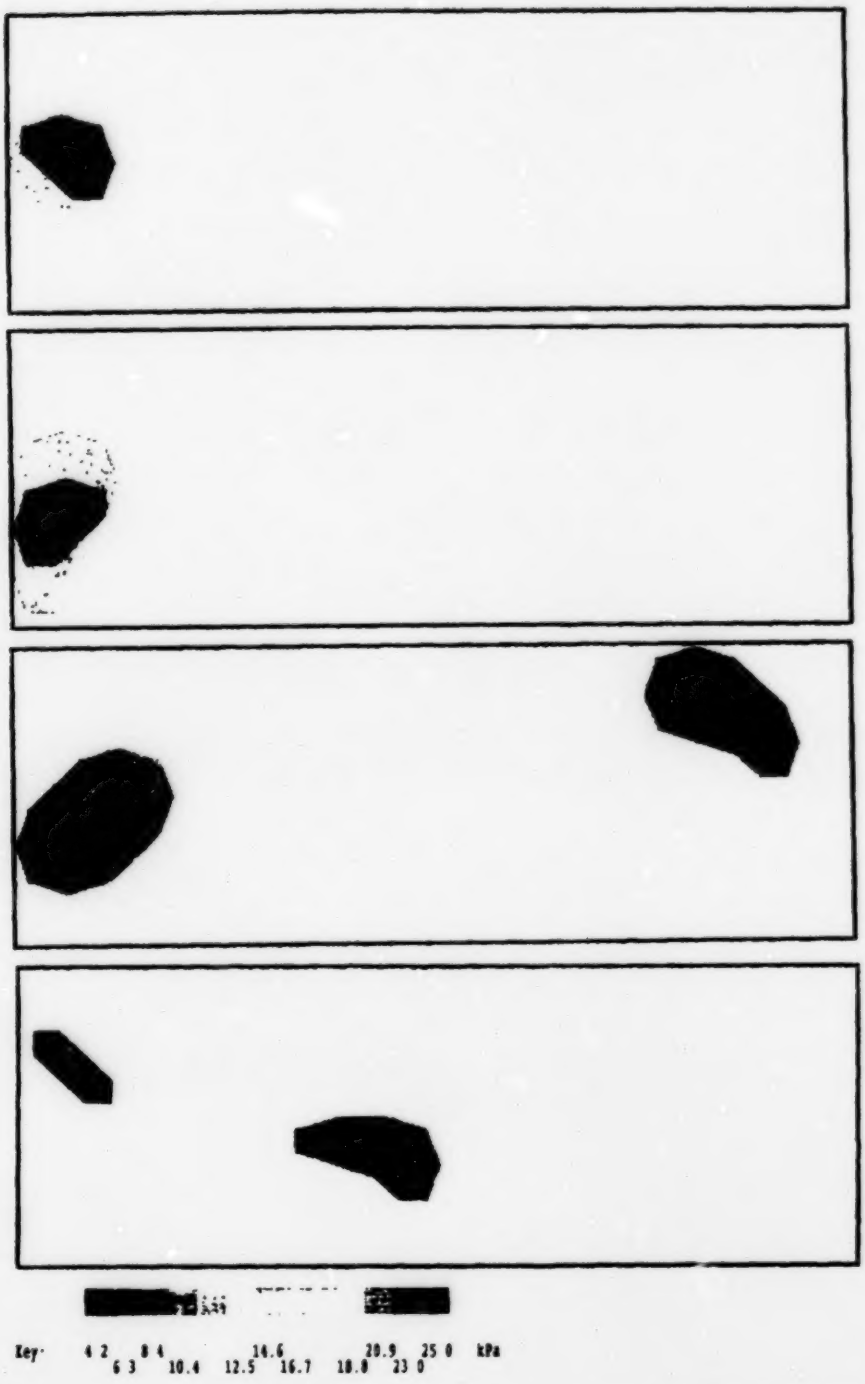


Figure 8 – Pressure plots for posterior shoulder for low, middle, high and alternate load locations respectively

4.0 Discussion:

4.1 Human Results

4.1.1 Physiological Results:

There was no significant difference in the repeated measures ANOVA between load locations and oxygen consumption under the conditions that were tested in this experiment (Table 1). The result agreed with the study performed by Bobet and Norman (3) which reported that there was no discernable difference in energy cost (as extrapolated from heart rate) based on varying the location of the COG over a 90 m walkway at 5.6 km/h while carrying a 19.5 kg pack. Their results, however, disagreed with the results of Datta and Ramanathan (5) who reported that the double pack proved less costly in terms of energy than six other forms of load carriage including the standard backpack carrying 30 kg at 5 km/h for 20 minutes. Legg and Mahanty (15) also reported that the double pack method of load carriage was more energy efficient than the 24.9 kg backpack worn for 1 hour while marching at 4.5 km/h. The main factors that differ in these experiments are the loads and the duration of the testing period. Because energy costs have been shown to increase with load and this result is constant within each scientific study, then task duration and methods of measuring energy cost are the main study differences. Perhaps if the current test duration had been longer than 15 minutes, similar results as obtained by other researchers (5, 15), may have occurred.

4.1.2 Biomechanical Results:

The angles that were examined were the trunk lean and total body lean, both of which were significantly different by load location for all alternate loads and between the low and high permutations ($p < 0.05$) (see Table 2). For a subject to maintain balance, trunk and total body lean are employed to move the load over the body's center of gravity. Placing the load more vertically in line with the body's center of gravity reduces the moment about the hips caused by the backward pull of the backpack. The alternate method reduced the backward moment by dividing the load between the front and back of the subject. With this distribution, the line of action of the force caused by the load then passes through the center of gravity of the body, reducing the rotary moment due to pack position. Bobet and Norman (3) clarified that, in general, loads placed higher than the body's center of gravity cause an excess forward moment. Placement of the load lower than the COG causes an excess backward moment. Movement of the load over the body's COG allows for the line of action of the load to fall in the same line as the body's mass and therefore will reduce the muscle effort required to counter the load moments. This explanation allows the subject to be in the most stable position for standing, however, the theory breaks down for walking where the COG must be placed in front of the feet for forward motion. In this condition, a low COG is poorest since the subject must use trunk or body lean to move the COG in front of the feet.

4.1.3 Subjective Results:

The subjective responses from both the initial and follow-up questionnaires indicated that the lower the load placement, the poorer the subjects rank overall acceptability. Subjects reported that this lower load placement caused them to lean farther forward. This excess lean resulted in soreness of postural and neck muscles that are required to be constantly active in order to lean forward yet hyperextend the neck to see forward. There is a postural benefit to carrying the load higher. Figure 5 shows that the higher the load was placed, the closer to baseline are both the trunk and total lean angles. However, when the load was placed at the high end of the backpack, load stability decreased, which would make it unsuitable for uneven terrain. This may have increased muscular activity in the shoulder area during gait thus not reducing reported shoulder discomfort. These angles, however, were significantly greater than the angles that were recorded when the load is balanced on the front and the back ($p<0.05$). The benefits of carrying the load balanced on the front and back are better maneuverability and a reduction in back stresses. The downside of the alternative method was little or no skin-air circulation that leads to thermal discomfort (see Figure 6).

Using the subjective responses, a numerical ranking of all four load locations was possible. The responses indicated that the alternative method was the most preferred followed by the high placement. The responses also indicate the low placement was the least preferred. The relative importance of physiological, biomechanical or subjective variables is not known. For example, in selecting between high and alternative positions, which factor is more important – maneuverability or thermal comfort? Future research should be directed toward development of a weighting factor for each family of tests to determine their relative importance to the subjects.

4.2 Load Carriage Simulator Results:

4.2.1 Reaction Forces and Moments:

Computation of reaction forces and moments was performed using a standardized protocol on the load carriage simulator to examine the load transfer effects of varying the location of the load mass. The reaction forces represent the force that a person must apply at the hip to counteract the off-centre forces that are applied by the load carriage system itself. The moments reflect the quantity of counter balancing that must occur by the muscles across and above the hips to offset any rotation created by normal gait and the pack. In both situations, the greater the force or moment required to maintain balance, the greater the soldier's local and overall effort which could lead to discomfort, fatigue or pain. There is very little comparative data in the scientific literature, to determine what should be considered excessive forces and moments during backpacking. Most research in this area comes from cadaveric spinal column tissue tolerance data.

For balance, the manikin was set at 10°, 16° and 18° for the high, middle and low locations respectively. These settings are similar to the subject trunk angle positions reported in Figure 5 According to Winter (32), normal walking without load requires trunk angles that are slightly biased forward of vertical. The alternate load carriage strategy changes this value to 0° on the simulator and 5° for subjects on treadmill walking.

Another factor which was indicative of muscular effort were the moments of force needed to counter-balance the off-center body plus pack COG needed for locomotion. The alternate and high load distributions demonstrated smaller M_y (antero-posterior) moments, whereas the low and

middle distributions had higher M_y moments This indicates that the alternate load distribution, followed by the high distribution, would require less muscular effort and therefore demonstrate easier pack control. It is expected that this control would be an asset for mobility as well as overall comfort (29) The high load distribution showed inferior control of the M_x (medio-lateral) moment which indicated potential for increased shoulder pressure and a particular sensitivity to off-centre loading (29).

4.2.2 Skin Contact Pressure:

Table 6 shows the values measured at the anterior shoulder, posterior shoulder, upper lumbar, and iliac crest for all four load distributions. Although there is no general consensus on the magnitude of pressures that are safe for the human body, blood flow is occluded at 14 kPa and thus researchers have recommended this value as a maximum exposure rate over an eight hour period to prevent necrosis of the skin (9). Studies have also shown that average pressures on the shoulders that exceed 20 kPa was the threshold for perceived discomfort ratings in 95% of soldiers when marching with 32 kg over 6 km, therefore this value was recommended as a threshold limit for typical load carriage applications (9, 29).

Figures 7 and 8 show the pressure plots for the various pressure sensor locations and the different load locations. Average pressure over all sensors correlated positively with average discomfort ratings from the subjects ($r=0.815$). In the shoulder region pressure values ranged from just above 9 kPa for the alternate load location to almost 23 kPa in the middle distribution. These high pressure values in the shoulder for all load locations except alternate had been correlated with low posterior hip discomfort in previous studies (29) and had correlated with discomfort ratings in this study. Pressures in the lumbar and iliac crest were consistently higher

for all load distributions with the exception of the alternate load location that reported near zero values in both regions. Overall examination of the average pressure indicated that the alternate load distribution that will result in the least amount of discomfort. This finding was confirmed by soldier's subjective comfort ratings.

Peak forces can change depending on the body structure employing the load carriage system, the clothing that the subject is wearing, the task that they are performing and the location of the load. A value of 120 kPa is considered a conservative threshold limit for peak pressures in the shoulder, lumbar and hip areas. The high load location elicited peak values that were higher on average than other load locations. Subjects reported this perception of high pressure in the neck, shoulders, and lower back.

5.0 Conclusions, Reservations and Recommendations:

5.1 Conclusions:

Under the conditions tested in this study it can be concluded that load location does not significantly affect physiological variables, such as oxygen consumption. However, a longer activity duration is required to confirm this result. Trunk angle and total lean angle vary significantly with load location. A lower load placement increases both trunk angle and total lean angle. Subjective evaluation shows that the preference for load location is, above all, balanced on the front and back, with its biggest handicap being thermal comfort. The second preferred load location was highest on the back. Pressures in all of the tested regions were lowest in the balanced load distribution. Average pressures in the lumbar and iliac crest area increased as the load was moved down the back, but total shoulder pressures remained unchanged. Comparable pressure points were also identified by subjects in the questionnaires thus confirming the utility of the LC Simulator test.

5.2 Recommendations:

In order to further determine whether load location affects physiological and biomechanical factors:

- examine the muscular effect of increased trunk and total lean
- test load distributions under longer activity conditions
- develop weighting system for correlated variables

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14. ABSTRACT

(U) The purpose of this study was to determine the effect of varying the centre of gravity of the load on physiological, biomechanical, and subjective factors of experienced soldiers. A secondary purpose was to examine the relationship of these factors to a standardized load carriage (LC) simulator test. Twenty-two experienced soldiers marched on a treadmill at 5.6 km/hr for 15 minutes carrying a modified backpack, created by US Army Natick Research Laboratory, which consisted of the ALICE pack frame and a movable load box containing 36kg. In addition, a load carriage vest was used to examine a balanced load distribution. Physiological measures were collected using oxygen consumption (VO2) and heart rate. Biomechanical measures were collected from video images of gait to calculate trunk and body lean. Subjective measures were recorded of pressure points using a body scan image, as well as general assessments of each system and an overall ranking. Physiological measures were not able to discern statistical differences between load locations, perhaps because of the short test duration. Biomechanical measures revealed that trunk and body lean were significantly reduced with the balance method, followed by the higher centre of gravity load location. Subjective results revealed an overall prefernece for a balanced load, except for its associated heat stress, with the next most favoiured load locatin being a high centre of gravity. The same pattern of biomechanical values was revealed through a decrease in Fz with lower load locations and an increase My with higher load location when th eLC Simulator was used to test each condition. Pressure measurements were all above 20kPa with the balanced load having reduced pressures in comparison to other strategies. Average pressures in the lumbar and iliac crest areas increased as the load was moved down the back, but the total shoulder pressures remained unchanged. It was concluded that, for marching order, balanced loads outperform all other backpack strategies, although thermal stress needs to be overcome. The next best solution is one that has the centre of gravity of the load at a high location in the pack.

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(U) load centre of gravity; backpack; load carriage; physiology; biomechanics; load location

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